A Multiphysics Approach to the Modeling of Biological Prosthetic Heart Valves

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Introduction: Computational simulations can play an important role in enhancing design, evaluation and interventional planning of Biological Heart Valves (BHV). To take full advantage of computational approaches, modeling strategies must describe accurately valve geometry, mechanical behavior of leaflets biological tissue and loading condition.

Valve Geometry: Examined BHV consist of a leaflet mounted on a supporting frame, whose complex geometry was created with a CAD software and imported using _Live-Link_ and _CAD import modules_

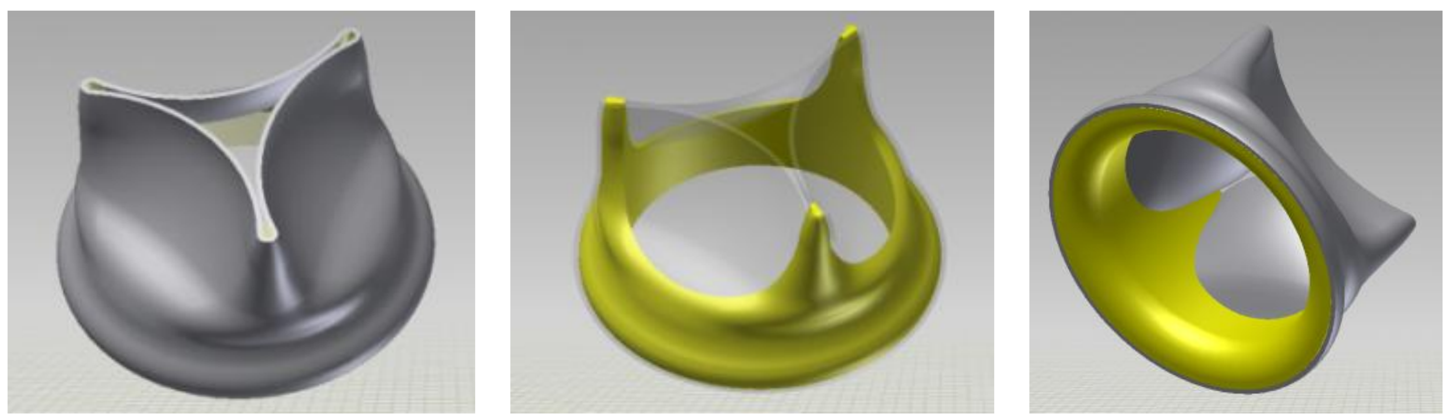


Figure 1. BHV model consisting of leaflet and stent

Constitutive modeling: Valve leaflets were made of chemically treated bovine pericardium, a soft biological tissue whose complex mechanical behavior was modeled considering both isotropic and anisotropic hyperelastic laws implemented in the _Structural Mechanics module_. _PDE module_ was used to control preferred fiber orientations on the valve leaflet.

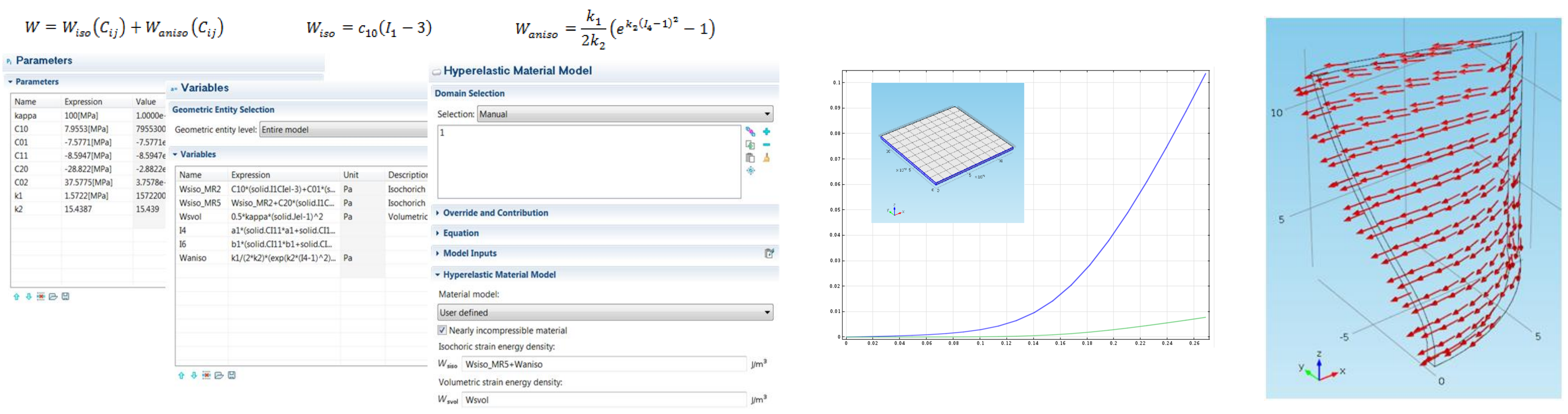


Figure 2. Constitutive law implementation and preferred fiber orientation

Computational models: Both structural and fluid structure interaction approaches were implemented. ***Moving Mesh module*** and ***CFD module*** *were added* to carry out fluid structure interaction

FEM Models (Structural only)

Load is applied to valve leaflet as a time varying pressure.
Both Isotropic or Anisotropic hyper-elasticity considered.

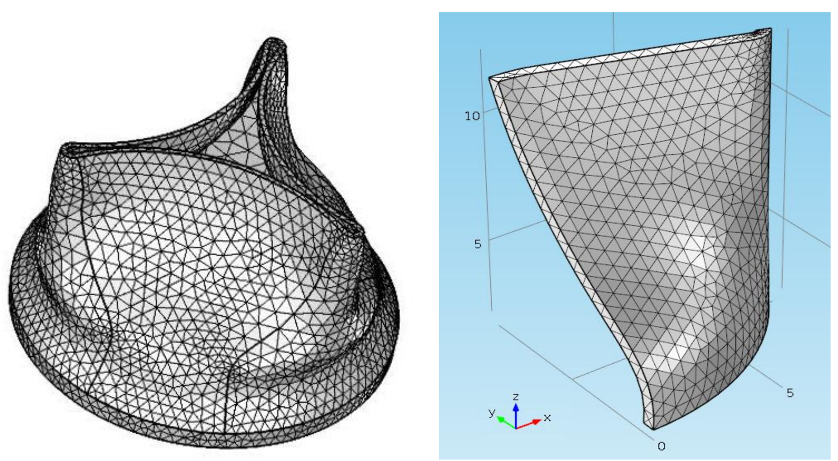
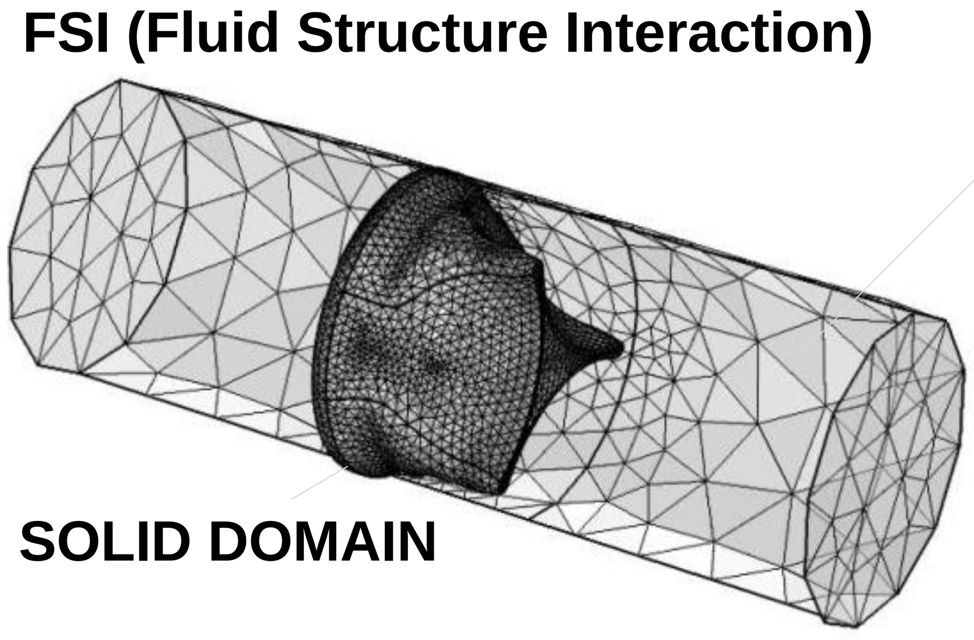


Figure 3. Full and 1/6th valve model

FSI (Fluid Structure Interaction)



SOLID DOMAIN

Fluid forces applied as boundary load at Fluid-solid interface. Elastic or hyper-elastic isotropic behavior.

FLUID DOMAIN

Navier-Stokes equations solving for the velocity field u = (u,v) and pressure p.
B.C: Inlet/outlet pressures or flow rates under stationary or transient conditions.
Blood considered as newtonian fluid

MOVING MESH

Mesh nodes pertubed so they conform to the moved boundaries by prescribing structural displacements as mesh displacement at the fluid/solid interface

Results: By means of structural analyses (FEM) the stress state and deformation field could be investigated. The presence of highly stressed areas in the commissural region can be noticed.

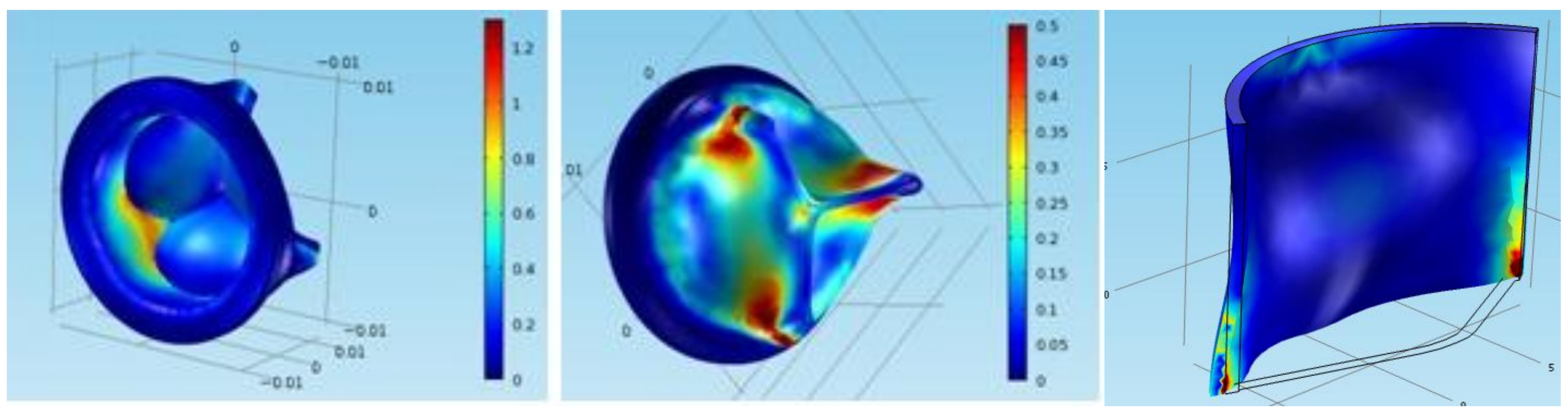


Figure 4. Contour maps of Von Mises stress for structural models

FSI analyses are particularly useful when considering the opening phase, since in this case the deformation of valve leaflets depends on flow conditions, which in turn depends on the valve response.

In parallel to numerical simulations the valve was subjected to stationary and transient flow tests on a valve test bench available at the University of Brescia. Predicted transvalvular pressure gradient and progressive valve opening were satisfactorily in agreement with experimental measurements on a valve test bench.

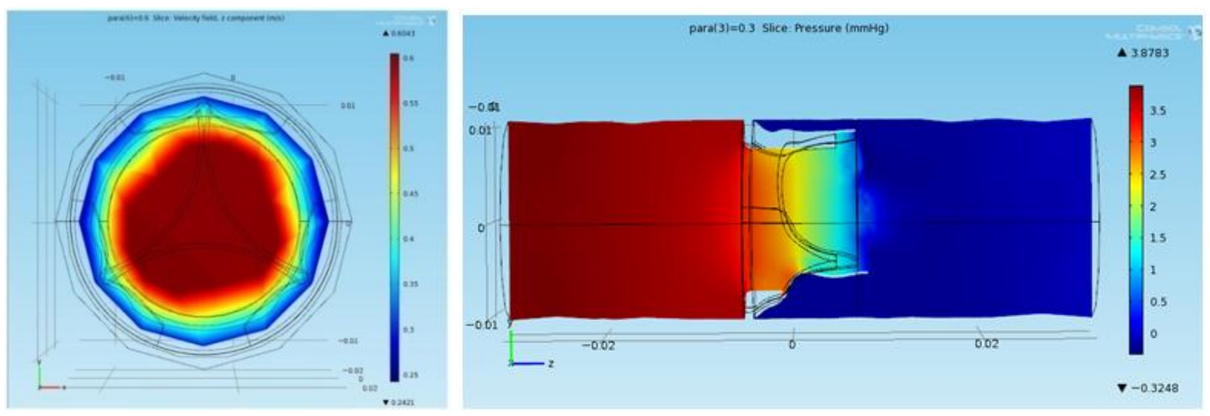


Figure 5. Fluid velocity and transvalvular pressure gradient for valve + fluid channel model

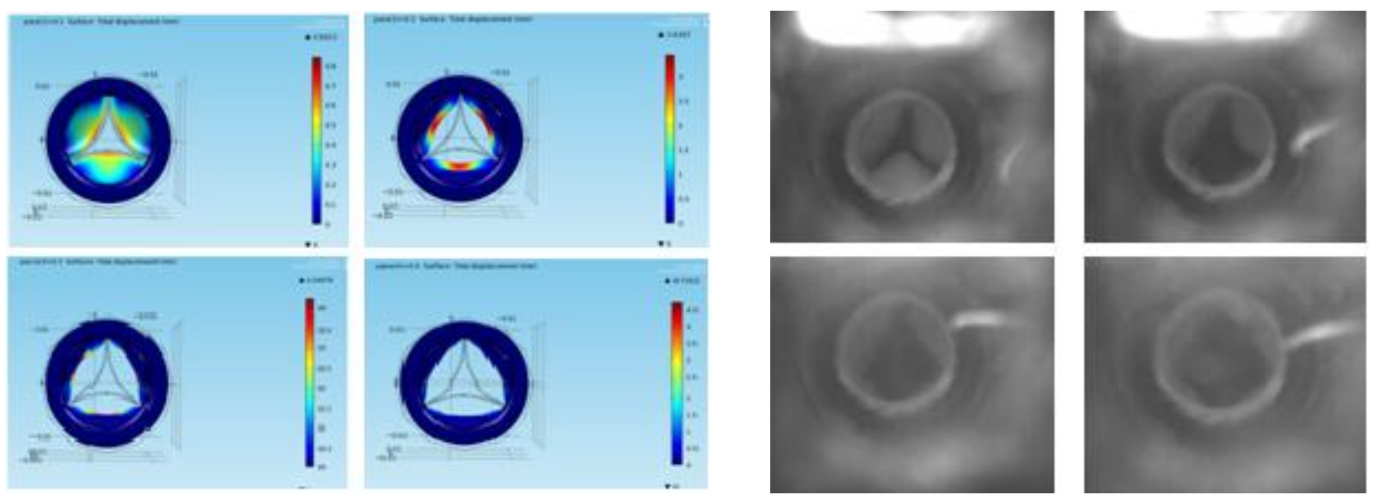


Figure 6. Comparison of predicted and experimental progressive valve opening

Conclusions and future work: The approach adopted in the present study demonstrates that if realistic valve geometries are combined with accurate material properties the use of computational approaches that features both structural and fluid-dynamic analyses can yield to very realistic results. Future work involves considering more complex models of test bench or anatomy of aortic root

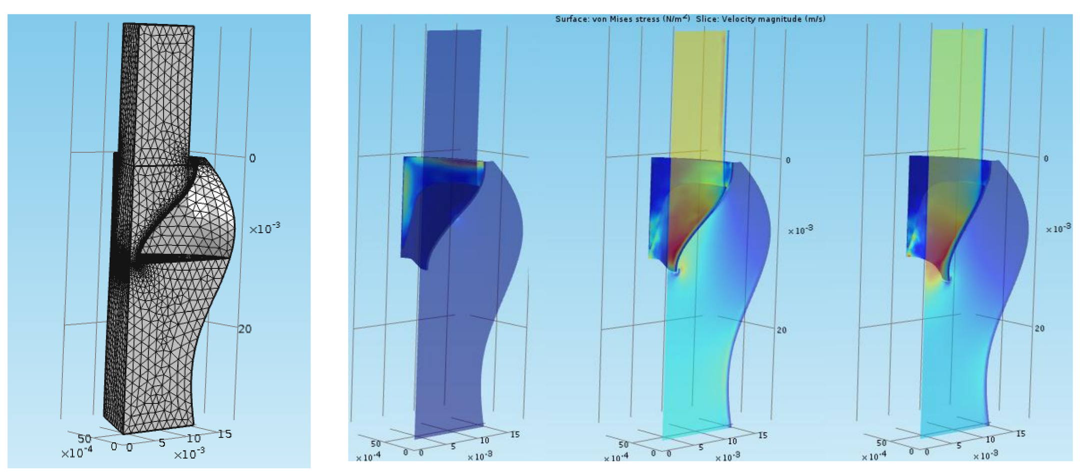


Figure 7. FSI simulation of Valve + valsalva sines (1/6th)

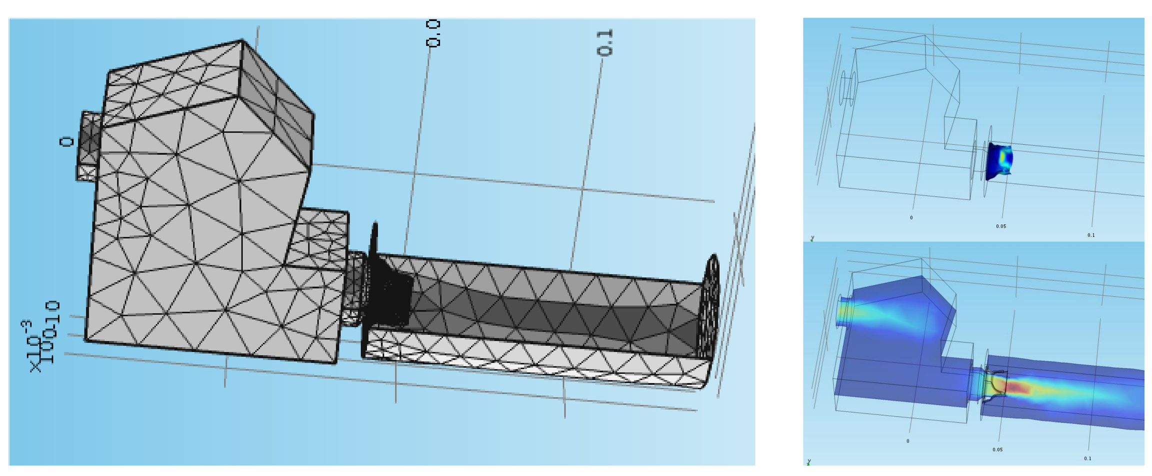


Figure 8. FSI simulation of valve + test bench

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